Factors Influencing Choice of Procedure in Transposition of the Great Arteries: A Decision Analysis Approach

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Clinicians have a difficult choice between the arterial switch (Jatene et al.) and the atrial baffle operation (Mustard or Senning) for transposition of the great arteries. The surgical decision is essentially a determination of whether the long-term course after the arterial switch procedure (thought to be more favorable than after the atrial baffle procedure) plus elimination of presurgical attrition with the atrial baffle is substantial enough to offset the higher early mortality rate associated with the arterial switch.

Decision analysis was undertaken to answer the following questions: 1) are there clinical circumstances under which published surgical results support a clear procedure of choice in transposition of the great arteries? and 2) what short- and long-term outcomes must be anticipated for the arterial switch to compare favorably with the published experience with the atrial baffle? A decision tree was constructed accounting for the major variables influencing mortality and morbidity in the surgical management of transposition of the great arteries.

Presuming that the arterial switch has moderate advantages over the atrial baffle in terms of late morbidity and mortality for simple transposition of the great arteries at an institution with average results from the atrial baffle, the early mortality rate of the arterial switch must be <24% to recommend the switch operation. Assuming extremely good surgical results from the atrial baffle, an early mortality rate of the arterial switch <20% is required to recommend the switch procedure over the atrial baffle operation. The poor results with the atrial baffle in transposition with ventricular septal defect make the arterial switch the procedure of choice, even when early mortality rates for the switch procedure are as high as 39%.

Careful reevaluation of the surgical results of the arterial switch procedure is imperative to establish that its high early surgical mortality rate is, indeed, offset by low rates of late mortality and morbidity. Decision analysis is an ideal tool for clinicians at specific institutions to account for unique institutional variations in surgical results.

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The arterial switch procedure originally described in 1975 by Jatene et al. (1) emerged in the 1980s (2–7) as a promising technique for the treatment of transposition of the great arteries. Clinicians must make a difficult choice between the arterial switch and the atrial baffle (Mustard or Senning) operation introduced in the late 1950s and early 1960s for patients with transposition of the great arteries. Considerations that weigh heavily in this decision include 1) the immediate surgical mortality rates for the arterial switch and atrial baffle procedures; 2) the long-term mortality rates and the anticipated degree of physical limitation associated with either procedure; 3) the preoperative attrition rates for patients awaiting either procedure; and 4) the differential influences of associated congenital heart defects (for example, ventricular septal defect) on the short- and long-term results of either operation. Further complicating this decision is the lack of follow-up information on patients undergoing an arterial switch operation beyond 15 years compared with the nearly 30 year follow-up data on the atrial baffle procedure.

Because of the complexity of this decision, Spiegelhalter and Rigby (8) used the problem of surgical choice in transposition of the great arteries to illustrate how to apply decision analysis in pediatric cardiology. A wealth of surgical and clinical experience with transposition of the great arteries has been reported more recently, prompting this reappraisal. We describe a decision tree model of the surgical approach to transposition in order to answer the following questions: 1) are there clinical circumstances under which published surgical results indicate a clear procedure of choice in transposition? and 2) what short- and long-term outcomes must be anticipated for the arterial switch procedure to compare favorably with the published experience with the atrial baffle operation?

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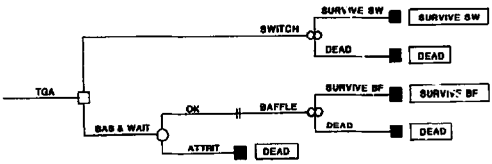


Figure 1. The decision tree for surgical choice in transposition of the great arteries (TGA). Standard notation for node type is used: □ = decision node; ○ = chance node; ‖ = label node; ∞ = Markov node; ■ = terminal node. The upper limb denotes the sequence of events after selection of arterial switch. Alternative outcomes after switch include survival (SURVIVE SW), which occurs with a probability of pSURVIVE SW, and death (DEAD), which occurs with a probability of 1-pSURVIVE SW. The lower limb shows the sequence of events after selection of atrial baffle. BAS & WAIT indicates that balloon atrial septostomy is performed and the patient is allowed to grow. This is associated with an attrition rate (ATTRIT) resulting in death. The probability of survival (OK) at the time of atrial baffle is 1-pATTRIT. Alternative outcomes after the atrial baffle procedure include survival (SURVIVE BF), which occurs with a probability of pSURVIVE BF, and death (DEAD), which occurs with a probability of 1-pSURVIVE BF.

Methods

Using a commercially available decision tree computer program (9) and standard decision analysis methodology (10,11), a decision tree was constructed to account for the major variables influencing mortality and morbidity in the surgical management of transposition of the great arteries (Fig. 1). Factors that could be varied for purposes of analysis include the immediate survival rate for the arterial switch procedure (pSurvive Switch), the immediate survival rate for the atrial baffle procedure (pSurvive Baffle) and the attrition rate for patients awaiting the atrial baffle procedure (pAttrition). Long-term survival after either operation was modeled as a Markov process (12) with the yearly survival rate R_1 for postoperative arterial switch and R_2 for postoperative atrial baffle. Long-term quality of life after surgery was designated Q_1 for postoperative arterial switch and Q_2 for postoperative atrial baffle (see Appendix). Current published reports (2–7, 13–18) of surgical treatment results for transposition of the great arteries were reviewed to provide data on surgical mortality, long-term survival and quality of life for use in this analysis.

Three-way threshold analysis for R_1, Q_1 and pSurvive Switch was carried out for determination of threshold values above which the outcome of the arterial switch operation equaled or exceeded the outcome of the atrial baffle procedure in three specific cases: 1) a standard published experience with the atrial baffle in simple transposition (atrioventricular concordance, ventriculoarterial discordance without ventricular septal defect and without severe pulmonary outflow obstruction) in which $R_2 = 0.9965$, $Q_2 = 0.85$ and pSurvive Baffle = 0.944; 2) an exceptionally good published experience with simple transposition in which $R_2 = 0.9965$, $Q_2 = 0.85$ and pSurvive Baffle = 0.99 (13); and 3) a standard published experience with transposition with large ventricular septal defect in which $R_2 = 0.9877$, $Q_2 = 0.85$ and pSurvive Baffle = 0.84.

Results

Simple transposition: the standard atrial baffle experience. Given a standard reported quality of results after the atrial baffle operation, a three-way threshold analysis of R_1, Q_1 and pSurvive Switch is shown in Figure 2. With the most optimistic view of ongoing survival rate ($R_1 = 1.0$), and quality of life ($Q_1 = 1.0$) after the arterial switch, an early surgical survival rate of ≥66% is required for the arterial switch to be considered superior to the atrial baffle (point A, Fig. 2). A skeptical view of the arterial switch may contend that long-term mortality and quality of life are essentially equal to those after atrial baffle ($R_1 = 0.9965$, $Q_1 = 0.85$). In that case (point B, Fig. 2), an early arterial switch survival rate of ≥88% would be necessary to recommend it as the procedure of choice. Perhaps it is most reasonable to assume that ongoing survival rate and quality of life are better but not perfect after the arterial switch than after the atrial baffle ($R_1 = 0.9982$, $Q_1 = 0.925$). In that case, an early surgical survival rate of 76% is the threshold value above which the arterial switch procedure can be recommended (point C, Fig. 2).

Simple transposition: the exceptionally good atrial baffle experience. Some institutions have very favorable experience with the baffle procedure against which the arterial switch results must be compared. The results of three-way threshold analysis of R_1, Q_1 and pSurvive Switch are shown

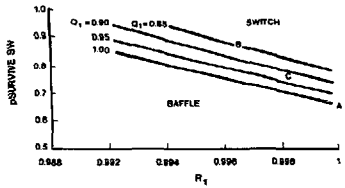


Figure 2. Three-way threshold analysis for conditions at which the utility of arterial switch equals the utility of atrial baffle for the standard surgical experience with transposition with intact ventricular septum using atrial baffle. The ongoing survival rate after arterial switch (R_1) is shown on the **horizontal axis** and initial surgical survival rate for arterial switch (pSURVIVE SW) is shown on the **vertical axis**. The **lines** indicate threshold values of quality of life after arterial switch (Q_1), separating conditions favoring arterial switch **(to the right and above)** from conditions favoring atrial baffle **(to the left and below)**. A reflects assumptions of no ongoing mortality or morbidity after arterial switch. B indicates assumptions of ongoing mortality and morbidity after arterial switch comparable with those after atrial baffle. C reflects assumptions of ongoing mortality and morbidity intermediate between A and B.

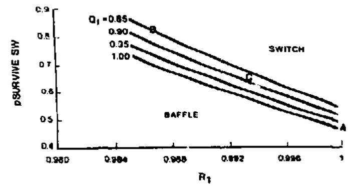
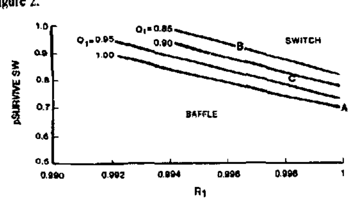


Figure 4. Three-way threshold analysis for conditions at which the utility of arterial switch equals the utility of atrial baffle for the standard surgical experience with transposition and ventricular septal defect using atrial baffle. Abbreviations and format as in Figure 2.

for this circumstance in Figure 3. Assuming that ongoing survival rate and quality of life are better but not perfect after arterial switch than after atrial baffle (R_1 = 0.9982, Q_1 = 0.925) (point C, Fig. 3), a ≥80% early surgical survival rate is required to recommend the arterial switch procedure.

Transposition with ventricular septal defect. Figure 4 shows the results of a three-way threshold analysis of R_1, Q_1 and pSurvive Switch given the standard reported quality of results after the atrial baffle procedure in transposition with ventricular septal defect. Assuming that ongoing survival rate and quality of life are better after arterial switch than after the atrial baffle but are not perfect (R_1 = 0.994, Q_1 = 0.925), an early surgical survival rate of 61% or better is required to favor arterial switch over atrial baffle (point C, Fig. 4).

Figure 3. Three-way threshold analysis for conditions at which the utility of arterial switch equals the utility of atrial baffle for an exceptionally good surgical experience with transposition and intact ventricular septum using atrial baffle. Abbreviations and format as in Figure 2.



Discussion

Implications for choice of transposition surgery. The arterial switch operation has theoretic advantages over the atrial baffle procedure in that the left ventricle generates the systemic blood pressure (reducing the risk of late right ventricular failure associated with the atrial baffle) and extensive atrial suturing is not required (reducing the likelihood of late sick sinus syndrome seen after atrial baffle). The considerations suggest that the long-term mortality and morbidity associated with the switch procedure could be substantially better than that of the atrial baffle (6). In view of reports of reoperation (2,3) and late death (2,19), it is inappropriate to assign a zero ongoing mortality and morbidity rate to the long-term outcome of arterial switch. It is realistic to assume values for long-term mortality and morbidity associated with the arterial switch procedure that are intermediate between zero and those after atrial baffle (point C, Fig. 2 to 4).

For transposition with intact ventricular septum in an institution with average results from the atrial baffle, the early surgical mortality rate for the arterial switch procedure must be <24% to undertake the arterial switch as a general treatment policy. In institutions with a very low mortality rate from the atrial baffle procedure (14), the early surgical mortality rate for the arterial switch should be ≤20% to justify the switch procedure over the atrial baffle. Although some institutions have had arterial switch results that meet these criteria, others clearly have not (7). The poor results of baffle operations in transposition with ventricular septal defect (17,18) make arterial switch the procedure of choice, even when early mortality rates for the switch operation are as high as 39%.

Comparison with previous analysis. Spiegelhalter and Rigby (8) suggested that a 44% initial mortality rate for the arterial switch procedure might be acceptable if a late postoperative yearly mortality rate of only 0.3% was achieved. This is substantially higher than the 24% initial mortality rate for the switch procedure accepted in the present analysis of simple transposition. Two factors account for this difference. First, a 2% postbaffle yearly mortality rate was assumed in the previous work. This high figure was derived from surgical results during the late 1960s and early 1970s (20), which included some instances in which Dacron baffles were used in some cases of transposition with ventricular septal defect. Modern surgical results (13–18) for simple transposition do not confirm this high ongoing postbaffle mortality rate. Second, the previous analysis incorporated a 14% mortality rate in the first year of life after balloon septostomy. This is an overestimation of risk; a more recent (7) prospective determination of the prebaffle mortality rate (5%) in simple transposition was used in this report.

In contrast to Spiegelhalter and Rigby (8), we estimated the postoperative quality of life and considered that quality after arterial switch is better than or equal to that after atrial baffle. Early experience with arterial switch probably justifies this, based on the low incidence of postoperative arrhythmias in these patients, thus reducing the need for antiarrhythmic medications and pacemakers and decreasing the chance of sudden unexpected death (2–7).

Future directions. Although it is premature to state categorically that arterial switch is the preferred approach for transposition of the great arteries, some reported surgical experiences appear to justify it for both simple and complex transposition. This assertion is tentative because at present, the long-term arterial switch results are *assumed*, not known. Careful long-term follow-up evaluation after arterial switch is imperative to establish that these favorable assumptions are indeed true. Decision analysis is well suited for such ongoing evaluation because 1) the assumptions underlying the decision are stated explicitly; 2) the assumptions can easily be changed and the decision reanalyzed in light of new data; and 3) there is flexibility to account for unique institutional variations in the surgical experience for both arterial switch and atrial baffle procedures.

Appendix

Measures of Outcome of Transposition Surgery

There are many indicators of hemodynamic outcome from transposition surgery, including ventricular function variables, heart size, need for antiarrhythmic medications or pacemaker, or both, and persistent left to right or right to left shunt. What really matters to the patient, however, is the length and quality of life that the hemodynamics permit. Therefore, we elected not to use hemodynamic features to assess outcome, but rather to model duration of life as a Markov process and estimate quality of life from reported clinical experience (13–15).

Determination of postoperative quality of life (Q_2) is a difficult problem. According to the validation study of Kaplan et al. (21), the presence of a symptom/problem complex characterized by "taking medication or staying on a prescribed diet for health reasons" decreases a patient's perceived well-being from a control value of 1.00 to 0.85. No specific adjustment for living in fear of sudden death or fear of subsequent reoperation is given by Kaplan et al. (21); however, if the symptom/problem complex features "spells of feeling upset, depressed, or crying," which may be a consequence of such fear, the perceived well-being is 0.74. Most long-term survivors of atrial baffle procedures are reported (13–15) to be in New York Heart Association functional class I, with a minority in class II. Severe psychiatric symptoms are not a prominent feature of the postoperative course for atrial baffle. On the basis of these considerations, the post-atrial baffle quality of life (Q_2) was set at 0.85 for the purposes of this analysis.

Reoperation after either the arterial switch or the atrial baffle procedure is a recognized but relatively unusual event (2,3,13–15). Mortality for reoperation is included as part of the yearly ongoing loss in the Markov process. Reoperation morbidity is not considered.

The value of the attrition rate for patients awaiting the atrial baffle procedure (pAttrition) was fixed at 0.05, based on recent prospectively accumulated data (7). Seventy Markov cycles were analyzed, which is equivalent to a 70 year horizon for analysis of the surgical decision. The initial utility of the atrial baffle was set at 1.0, accounting for the first half cycle of the Markov process and the 6 months of survival already accumulated before surgery. The initial utility of the arterial switch was set at 0.5, accounting for the first half cycle of the Markov process. Tail utilities and utility of the dead state were set at zero. The incremental utility of the atrial baffle in the Markov process was set at $0.9965^{(\text{cycle} - 1)}$ for the case of transposition with intact ventricular septum, based on a reported 10 year actuarial survival of 93.7% (14). The incremental utility of the atrial baffle procedure in the case of transposition with ventricular septal defect was estimated at $0.9877^{(\text{cycle} - 1)}$ on the basis of long-term data of Ashraf et al. (15).

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